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Read while write method in data storage device

Abstract:

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(72) Inventor:
Bartlett, Paul Frederick
Henleaze, Bristol BS9 4EJ (GB)

(71) Applicant:
Hewlett-Packard Company
Palo Alto, California 94304 (US)

(74) Representative:
Lawman, Matthew John Mitchell
Hewlett-Packard Limited,
IP Section,
Building 2,
Filton Road
Stoke Gifford, Bristol BS34 8QZ (GB)

(54) **Read while write method in data storage device**

(57) A method of writing data simultaneously to a plurality of tracks of a magnetic tape storage device whilst preventing elongate tape scratches corrupting blocks of data comprises: arranging a byte stream of user data into a plurality of codewords (600); distributing said codewords amongst a plurality of write heads (601); writing said codewords to a plurality of tracks (602); reading said data back from said plurality of tracks (603); verifying that said data has been written to tape successfully (604) and, if not, distributing said codewords amongst said plurality of read/write heads in a different order and re-writing said data to tape (605).

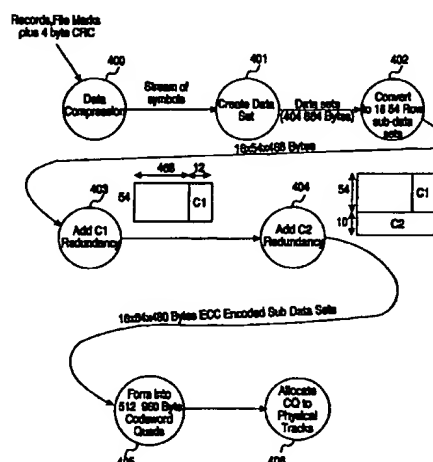


Fig. 4

	9	18	27	36	45	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216	225	234	243	252	261	270	279	288	297	306	315	324	333	342	351	360	369	378	387	396	405	414	423	432	441	450	459	468	477	486	495	504	513	522	531	540	549	558	567	576	585	594	603	612	621	630	639	648	657	666	675	684	693	702	711	720	729	738	747	756	765	774	783	792	801	810	819	828	837	846	855	864	873	882	891	900	909	918	927	936	945	954	963	972	981	990	999	1008	1017	1026	1035	1044	1053	1062	1071	1080	1089	1098	1107	1116	1125	1134	1143	1152	1161	1170	1179	1188	1197	1206	1215	1224	1233	1242	1251	1260	1269	1278	1287	1296	1305	1314	1323	1332	1341	1350	1359	1368	1377	1386	1395	1404	1413	1422	1431	1440	1449	1458	1467	1476	1485	1494	1503	1512	1521	1530	1539	1548	1557	1566	1575	1584	1593	1602	1611	1620	1629	1638	1647	1656	1665	1674	1683	1692	1701	1710	1719	1728	1737	1746	1755	1764	1773	1782	1791	1800	1809	1818	1827	1836	1845	1854	1863	1872	1881	1890	1899	1908	1917	1926	1935	1944	1953	1962	1971	1980	1989	1998	2007	2016	2025	2034	2043	2052	2061	2070	2079	2088	2097	2106	2115	2124	2133	2142	2151	2160	2169	2178	2187	2196	2205	2214	2223	2232	2241	2250	2259	2268	2277	2286	2295	2304	2313	2322	2331	2340	2349	2358	2367	2376	2385	2394	2403	2412	2421	2430	2439	2448	2457	2466	2475	2484	2493	2502	2511	2520	2529	2538	2547	2556	2565	2574	2583	2592	2601	2610	2619	2628	2637	2646	2655	2664	2673	2682	2691	2700	2709	2718	2727	2736	2745	2754	2763	2772	2781	2790	2799	2808	2817	2826	2835	2844	2853	2862	2871	2880	2889	2898	2907	2916	2925	2934	2943	2952	2961	2970	2979	2988	2997	3006	3015	3024	3033	3042	3051	3060	3069	3078	3087	3096	3105	3114	3123	3132	3141	3150	3159	3168	3177	3186	3195	3204	3213	3222	3231	3240	3249	3258	3267	3276	3285	3294	3303	3312	3321	3330	3339	3348	3357	3366	3375	3384	3393	3402	3411	3420	3429	3438	3447	3456	3465	3474	3483	3492	3501	3510	3519	3528	3537	3546	3555	3564	3573	3582	3591	3600	3609	3618	3627	3636	3645	3654	3663	3672	3681	3690	3699	3708	3717	3726	3735	3744	3753	3762	3771	3780	3789	3798	3807	3816	3825	3834	3843	3852	3861	3870	3879	3888	3897	3906	3915	3924	3933	3942	3951	3960	3969	3978	3987	3996	4005	4014	4023	4032	4041	4050	4059	4068	4077	4086	4095	4104	4113	4122	4131	4140	4149	4158	4167	4176	4185	4194	4203	4212	4221	4230	4239	4248	4257	4266	4275	4284	4293	4302	4311	4320	4329	4338	4347	4356	4365	4374	4383	4392	4401	4410	4419	4428	4437	4446	4455	4464	4473	4482	4491	4500	4509	4518	4527	4536	4545	4554	4563	4572	4581	4590	4599	4608	4617	4626	4635	4644	4653	4662	4671	4680	4689	4698	4707	4716	4725	4734	4743	4752	4761	4770	4779	4788	4797	4806	4815	4824	4833	4842	4851	4860	4869	4878	4887	4896	4905	4914	4923	4932	4941	4950	4959	4968	4977	4986	4995	5004	5013	5022	5031	5040	5049	5058	5067	5076	5085	5094	5103	5112	5121	5130	5139	5148	5157	5166	5175	5184	5193	5202	5211	5220	5229	5238	5247	5256	5265	5274	5283	5292	5301	5310	5319	5328	5337	5346	5355	5364	5373	5382	5391	5400	5409	5418	5427	5436	5445	5454	5463	5472	5481	5490	5499	5508	5517	5526	5535	5544	5553	5562	5571	5580	5589	5598	5607	5616	5625	5634	5643	5652	5661	5670	5679	5688	5697	5706	5715	5724	5733	5742	5751	5760	5769	5778	5787	5796	5805	5814	5823	5832	5841	5850	5859	5868	5877	5886	5895	5904	5913	5922	5931	5940	5949	5958	5967	5976	5985	5994	6003	6012	6021	6030	6039	6048	6057	6066	6075	6084	6093	6102	6111	6120	6129	6138	6147	6156	6165	6174	6183	6192	6201	6210	6219	6228	6237	6246	6255	6264	6273	6282	6291	6300	6309	6318	6327	6336	6345	6354	6363	6372	6381	6390	6399	6408	6417	6426	6435	6444	6453	6462	6471	6480	6489	6498	6507	6516	6525	6534	6543	6552	6561	6570	6579	6588	6597	6606	6615	6624	6633	6642	6651	6660	6669	6678	6687	6696	6705	6714	6723	6732	6741	6750	6759	6768	6777	6786	6795	6804	6813	6822	6831	6840	6849	6858	6867	6876	6885	6894	6903	6912	6921	6930	6939	6948	6957	6966	6975	6984	6993	7002	7011	7020	7029	7038	7047	7056	7065	7074	7083	7092	7101	7110	7119	7128	7137	7146	7155	7164	7173	7182	7191	7200	7209	7218	7227	7236	7245	7254	7263	7272	7281	7290	7299	7308	7317	7326	7335	7344	7353	7362	7371	7380	7389	7398	7407	7416	7425	7434	7443	7452	7461	7470	7479	7488	7497	7506	7515	7524	7533	7542	7551	7560	7569	7578	7587	7596	7605	7614	7623	7632	7641	7650	7659	7668	7677	7686	7695	7704	7713	7722	7731	7740	7749	7758	7767	7776	7785	7794	7803	7812	7821	7830	7839	7848	7857	7866	7875	7884	7893	7902	7911	7920	7929	7938	7947	7956	7965	7974	7983	7992	8001	8010	8019	8028	8037	8046	8055	8064	8073	8082	8091	8100	8109	8118	8127	8136	8145	8154	8163	8172	8181	8190	8199	8208	8217	8226	8235	8244	8253	8262	8271	8280	8289	8298	8307	8316	8325	8334	8343	8352	8361	8370	8379	8388	8397	8406	8415	8424	8433	8442	8451	8460	8469	8478	8487	8496	8505	8514	8523	8532	8541	8550	8559	8568	8577	8586	8595	8604	8613	8622	8631	8640	8649	8658	8667	8676	8685	8694	8703	8712	8721	8730	8739	8748	8757	8766	8775	8784	8793	8802	8811	8820	8829	8838	8847	8856	8865	8874	8883	8892	8901	8910	8919	8928	8937	8946	8955	8964	8973	8982	8991	9000	9009	9018	9027	9036	9045	9054	9063	9072	9081	9090	9099	9108	9117	9126	9135	9144	9153	9162	9171	9180	9189	9198	9207	9216	9225	9234	9243	9252	9261	9270	9279	9288	9297	9306	9315	9324	9333	9342	9351	9360	9369	9378	9387	9396	9405	9414	9423	9432	9441	9450	9459	9468	9477	9486	9495	9504	9513	9522	9531	9540	9549	9558	9567	9576	9585	9594	9603	9612	9621	9630	9639	9648	9657	9666	9675	9684	9693	9702	9711	9720	9729	9738	9747	9756	9765	9774	9783	9792	9801	9810	9819	9828	9837	9846	9855	9864	9873	9882	9891	9900	9909	9918	9927	9936	9945	9954	9963	9972	9981	9990	10000
1	10	19	28	37	46	55	64	73	82	91	100	109	118	127	136	145	154	163	172	181	190	199	208	217	226	235	244	253	262	271	280	289	298	307	316	325	334	343	352	361	370	379	388	397	406	415	424	433	442	451	460	469	478	487	496	505	514	523	532	541	550	559	568	577	586	595	604	613	622	631	640	649	658	667	676	685	694	703	712	721	730	739	748	757	766	775	784	793	802	811	820	829	838	847	856	865	874	883	892	901	910	919	928	937	946	955	964	973	982	991	1000																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
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Fig. 6

Description

Field of the Invention

5 [0001] The present invention relates to data storage devices and in particular although not exclusively to tape data storage devices having a capability of writing data simultaneously to a plurality of tracks.

Background to the Invention

10 [0002] In order to store digital electronic data, it is known to use magnetic tape data cartridges which are inserted into a tape drive unit having a plurality of read/write heads. Typically such magnetic tape storage devices may be used to back up data generated by a host device, eg a computer.

[0003] As the drive for greater data storage capacity necessitates narrower tracks on linear tape data storage devices, individual codewords are at greater risk of being corrupted during the write to tape process due to, for example, a
15 scratch on the magnetic coating of a tape storage medium.

[0004] It is known in tape storage devices to configure the write and read heads such that data written to tape can immediately be read back from tape to verify whether or not the data has become corrupted during the writing process. In the case of discrete blocks of data associated with, for example, the output of a computer, it may be possible to rewrite the corrupted codewords detected.

20 [0005] However, simply rewriting one bad block of a plurality of codewords that may be written to tape simultaneously using a plurality of read/write heads would necessitate that any subsequent codewords recorded on tape would need to be reordered. In addition, as the number of rewrite operations increases so the reordering of subsequently written data would become increasingly complex.

25 Summary of the Invention

[0006] The specific embodiments and methods according to the present invention aim to improve the writing of data in high data density tape systems having a plurality of read/write heads, and thereby improving the reliability of such devices.

30 [0007] Specific methods according to the present invention, recognize that if corrupted data is re-written to a plurality of tracks in a different track order to that of a previously written version of the data, then data previously effected by surface damage can be written to tape successfully.

[0008] According to a first aspect of the present invention there is provided a method of writing data to a data storage medium the method characterized by comprising the steps of:

35 partitioning said data into a plurality of codewords;

distributing said codewords amongst a plurality of write heads;

40 performing a write operation to write said codewords to a plurality of tracks of said data storage medium;

performing a read operation to read said codewords from said plurality of tracks;

if said codewords read from said plurality of tracks contain errors, then re-distributing said codewords originally written to said data storage medium in a different order amongst said plurality of write heads; and
45 performing a re-write operation to re-write said re-distributed codewords to a plurality of tracks of said data storage medium.

50 [0009] Preferably, said data storage medium comprises an elongate tape, and said write operation comprises a write pass along a length of said tape.

[0010] The said step of distributing codewords amongst a plurality of write heads preferably comprises distributing a plurality of Codeword Quads amongst said plurality of write heads. A set of four codewords is termed a Codeword Quad herein.

55 [0011] Preferably each of said plurality of Codeword Quads are allocated to a corresponding said write head.

[0012] Preferably, said step of performing a write operation comprises simultaneously writing said plurality of Codeword Quads onto said data storage medium through said write heads.

[0013] A said plurality of Codeword Quads may be arranged into a logical track block for writing to said data storage

medium simultaneously, and a position of an individual said Codeword Quad within said logical track block is indicated by an integer number.

[0014] A plurality of said Codeword Quads to be written simultaneously may be arranged into a logical track block;

5 said Codeword Quads of each said logical track block may be allocated to corresponding ones of said plurality of write heads in a first order, and

if an error is detected in said Codeword Quads once written to said data storage medium, said Codeword Quads of said logical track block are re-allocated to said write heads in said different order.

10

[0015] Preferably, a position of said Codeword Quads within said logical track block is denoted by an integer number.

[0016] Preferably, each of said Codeword Quads of a said logical track block corresponds with a respective one of said plurality of write heads.

[0017] A said first order may be determined by the expression:

15

$$\text{Track_Number} = \text{Mod} \left[\frac{(\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T}))}{\text{N_T}}, \text{N_T} \right]$$

20

where the Track_Number represents a number of an element of a logical track block, CQ_Number represents a number of a set of four codewords, Mod represents the integer remainder of a modulo division; and N-T represents a number of tracks simultaneously written.

[0018] Said different order may be determined by an expression:

25

$$\text{Track_Number} = \text{Mod} \left[\frac{(\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T}))}{\text{N_T}} - W, \text{N_T} \right]$$

30

where the Track_Number represents a number of an element of a logical track block, CQ_Number represents a number of a set of four codewords, Mod represents the integer remainder of a modulo division; W represents the state of a character which cycles through a sequence of integers 0 to M-1, where M represents the number of active tracks which can be written to simultaneously; and N-T represents a number of tracks simultaneously written.

35

[0019] Preferably, said data storage medium comprises a magnetic data storage medium, for example a cassette tape cartridge comprising an elongate band of tape wound about a reel.

[0020] The invention includes a data storage device comprising at least one read element and at least one write element, said device characterized by comprising means capable of writing data to a data storage medium and means capable of reading said written data from said data storage medium, wherein:

40

said write means is operable to partition said data into a plurality of codewords;

said write means is operable to distribute said codewords amongst a plurality of write heads;

45

said write means is operable to perform a write operation to write said codewords to a plurality of tracks of said data storage medium;

said read means is operable to perform a read operation to read the codewords from said plurality of tracks;

50

if said codewords read from said plurality of tracks are incomplete, then said device is operable to re-distribute said codewords originally written to said data storage medium in a different order amongst said plurality of write heads; and

said device is operable to perform a re-write operation to re-write said re-distributed codewords to a plurality of tracks of said data storage medium.

55

[0021] The invention includes a device capable of reading data recorded on a data storage medium, said data comprising a plurality of codewords, said codewords having been written to said data storage medium in a plurality of track

blocks, wherein each said track block comprises a plurality of codewords written to said data storage medium substantially simultaneously, wherein:

a plurality of codewords belonging to a first logical track block are written to a set of tracks in a first order; and

if said plurality of codewords have been erroneously written at said first position occupied by said logical track block, said plurality of codewords have been written to said plurality of tracks in a second order, at a second position on said plurality of tracks.

[0022] Said data storage medium optimally comprises a magnetic tape data storage medium.

[0023] The invention includes a method of rewriting corrupt data which protects against the effects of extended data to the storage medium.

Brief Description of the Drawings

[0024] For a better understanding of the invention and to show how the same may be carried into effect, there will now be described by way of example only, specific embodiments, methods and processes according to the present invention with reference to the accompanying drawings in which:

Fig. 1 illustrates schematically a plurality of paths taken by a read/write head relative to an elongate band of magnetic tape material according to a specific method of the present invention;

Fig. 2 illustrates schematically a general overview of a device configured to distribute a stream of data to a plurality of write heads and to write the data to a magnetic tape data storage medium;

Fig. 3 illustrates schematically a layout of a band group comprising a plurality of physical data tracks recorded onto a magnetic tape data storage medium according to a specific method of the present invention;

Fig. 4 illustrates schematically in general overview a process for redundancy coding and recording a byte stream of data from a host apparatus onto a magnetic tape data storage medium according to a specific implementation of the present invention;

Fig. 5 illustrates schematically the layout of a single block of process data from a host apparatus in the form in which it is allocated to a track of a magnetic tape storage medium according to a specific implementation of the present invention;

Fig. 6 illustrates schematically how the process codewords of a complete data set are allocated to a plurality of tracks of a magnetic tape storage medium according to a specific implementation of the present invention;

Fig. 7 illustrates schematically generalized process steps for writing data to a data storage medium, and rewriting any corrupted or incorrectly written data, during said data writing operation;

Fig. 8 illustrates schematically steps for writing data to tape, verifying that the data has been correctly written and rewriting corrupt data according to the specific implementation of the present invention; and

Fig. 9 illustrates schematically an example of how codewords are allocated to tracks of a tape storage medium where bad blocks have been rewritten to tape according to the specific implementation of the present invention.

Detailed Description of the Best Mode for Carrying Out the Invention

[0025] There will now be described by way of example the best mode contemplated by the inventors for carrying out the invention. In the following description numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent however, to one skilled in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

[0026] Specific methods according to the present invention described herein are aimed at magnetic tape recording devices having a substantially static read/write head in which an elongate tape is drawn past the head at relatively high speed, for example of the order 3 meters per second.

[0027] Reading and writing of data onto the tape may be carried out in both forward and reverse pass directions of the tape relative to the head, and a plurality of parallel data tracks may be read or recorded onto the tape simultaneously using a read/write head comprising a plurality of spaced apart read/write elements. However, the general methods disclosed and as identified in the claims herein, are not limited to static head devices or devices having high tape speeds.

[0028] In the following description a specific embodiment having 8 tracks simultaneously written to will be described. However, it will be recognized by the skilled person that the general methods disclosed herein may be applied generally to other track formats in which 2, 4, 16 or other numbers of tracks are written simultaneously.

[0029] Referring to Fig. 1 herein, there is illustrated schematically a physical layout of data recorded along an elongate band of magnetic tape by a read/write head of a magnetic data recording device as the tape is drawn past the head.

The read/write head contains a plurality of read elements and a plurality of write elements arranged to read or write a plurality of physical tracks of data along a tape simultaneously, resulting in physical tracks 100, 104 which are recorded parallel to each other along the length of the tape. The plurality of read/write elements are spaced apart from each other in a direction transverse to the direction of the tape, typically by a distance of the order 200 μm . Each read/write element is capable of reading or writing a physical track of width of the order 20 μm or so. The read/write head records a plurality of band routes along the tape in a path shown in Fig. 1 herein. Each band route contains a plurality of bands, each band comprising a plurality of physically recorded data tracks. Substantially a complete length of the tape is wound past the static read/write head in a single pass.

[0030] Ideally the tape winds its whole full length from a first end to a second end of the tape during a "pass" of the tape past the read/write head. In this specification a "write pass" is defined as a single passage of the tape past a write head for writing onto a single track, irrespective of whether the tape speed varies, or whether the tape stops during a pass. During a back up operation, the tape may traverse the read/write head in forward and reverse directions a number of different times, in a plurality of different write passes. A write pass may comprise a sequence of writes which cause data to be written sequentially along one or more tracks, which are themselves written in sequence.

[0031] Referring to Fig. 2 herein, there is illustrated schematically a data storage device capable of writing data to a data storage medium and reading said written data from said data storage medium, comprising: a device 201 which is operable to partition a stream of data from a host device into a plurality of codewords; a device 202 which is operable to distribute the codewords amongst a plurality of write heads; a plurality of write heads 220 - 227 which are operable to perform a write operation to write the codewords to a plurality of tracks of the data storage medium; a plurality of read heads 230 - 237 which are operable to perform a read operation to read the codewords from the plurality of tracks; a device 203 operable to verify if the codewords read from the plurality of tracks are incomplete. Device 204 which is operable to re-distribute incomplete codewords originally written to the data storage medium in a different order amongst the plurality of write heads.

[0032] In one embodiment of the present invention, the line of 8 write heads are followed by a parallel line of 8 read heads. Each head is switchable to perform either as a read head or a write head. The state of each head is switched on every change of direction of the tape so as to ensure that the read head is always "downstream" of the write head with respect to the direction of movement of the tape past the heads. In a second embodiment of the present invention, the line of 8 write heads are located between two parallel lines of 8 read heads. The read head that is used to read the data from tape in any given write pass is chosen so as to ensure that the read head is always downstream of the corresponding write head irrespective of the direction of movement of the tape past the heads.

[0033] Referring to Fig. 3 herein there is shown schematically the layout of a single band along a tape. Each band comprises a set of N tracks 301 formed during one write pass of the tape past one of a plurality M read/write heads. After recording one write pass along the length of the tape from the beginning of the tape (BOT) to the end of the tape (EOT), the plurality of read/write heads are moved in a transverse direction, with respect to the elongate direction of the tape, by a distance of the order 20 μm . Data is then written to the tape with the tape moving in the opposite direction to the previous write pass. The plurality of read/write heads trace a "serpentine" path on the tape 300 - 320. After each successive write pass the plurality of read/write heads are moved a further short distance of the order 20 μm in a transverse direction to the main length of the tape.

[0034] During the process of writing data to tape there is a risk that the data may not be correctly written to tape. This may occur, for example, if the coating of the tape has been damaged by a scratch. Should this occur it may not be possible to correctly recover the data from the tape.

[0035] According to the best mode presented herein, the data is read back off the tape immediately after having been written to tape during a same pass of the tape past the read/write heads. In this way the integrity of the data written to tape can be confirmed substantially at the same time as it is being written. If any of the data from one or more of the read/write heads has become corrupted on being written to tape, this is detected and the data can be rewritten at a point further along the main length of the tape. In the best mode herein, the order in which the rewritten data is presented to the read/write heads is varied by rotation in order to minimize the effects of scratches along the main length of the tape affecting the same rewritten data.

[0036] Referring to Fig. 4 herein, there is illustrated an encoding method for encoding user data prior to recording the

user data onto a plurality of physical data tracks as described hereinbefore.

[0037] The data as supplied by the host device computer is in the form of a variable length record which may be separated by file marks and in the best mode presented herein may have a length of up to $2^{24} - 1$ bytes. A 4 byte cyclic redundancy check (CRC) is added to the end of each record, forming a protected record. In step 400 a data compression algorithm compresses the protected records producing a stream of Symbols. In step 401 the Symbol stream is broken into data sets of 403884 bytes to which a 468 data set information table (DSIT) is appended to form a 404352 byte data set. In step 402 each data set is split into 16 sub-data sets each of 25272 bytes and each sub-data set is arranged into a 54 by 468 byte matrix arranged in rows and columns. In step 403 a (240, 234, 7) Reed-Solomon redundancy coding algorithm is applied to the 234 even numbered bytes in each row producing 6 C1 Error Correcting Code (ECC) bytes. These bytes are placed in the even number C1 parity locations for that row. Then the same Reed-Solomon code is applied to the 234 odd numbered bytes with resulting 6 C1 ECC bytes placed in the odd numbered C1 parity locations for that row. Each row of the matrix comprises one interleaved codeword pair of 480 bytes. The even numbered bytes form the first codeword of the codeword pair and the odd numbered bytes form the second codeword of the codeword pair. Thus 12 bytes of C1 parity information are appended to each row of the 54 by 468 byte matrices forming the 16 sub-data sets. In step 404, a (64, 54, 11) Reed-Solomon code is applied to each 54 byte column of the codeword pair matrix producing 10 C2 Error Correcting Code (ECC) bytes per column. The added 10 bytes of C2 ECC form ten additional codeword pairs. The resulting 64 by 480 byte matrices form ECC encoded sub-data sets each comprising 64 codeword pairs. An ECC encoded data set contains 491520 bytes comprised of 16 64x480 byte ECC encoded sub-data sets. Each row of each ECC encoded sub-data set is a 480 byte ECC encoded codeword pair. Thus there are 1024 ECC encoded codeword pairs per ECC encoded data set. In step 405, and referring to Fig. 5 herein, a codeword quad (CQ) is formed by combining a codeword pair header 500, a first codeword pair 501, a second codeword pair header 510 and a second codeword pair 511. The first and second codeword pairs in a codeword quad comprise the corresponding rows of the ECC coded sub-data sets 2R and 2R+1, where R takes the values 0 to 7. For example, the tenth codeword quad has a first codeword pair comprising the first row of sub-data set number 2 and a second codeword pair comprising the first row of sub-data set 3. The 1024 codeword pairs in the 16 sub-data sets form 512 codeword quads each of 960 bytes.

[0038] In step 406, codeword quads are allocated to each one of the plurality of read/write heads. In the best mode herein codeword quads are written simultaneously onto the tape in sets of 8 CQs, where for example 8 is the number of concurrent read/write heads each read/write head allocated to a corresponding respective physical tape track. One CQ of each set is written concurrently by a respective one of the write heads. The set of a CQ is determined by the expression:

$$\text{Set_Number} = \frac{\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T})}{\text{N_T}} \quad (1)$$

where the Set_Number is a number of a set of CQs, and CQ_Number is the number of the codeword quad to be allocated to the set, and N_T is the number of tracks simultaneously written in a write operation.

[0039] Each codeword quad is allocated to a particular active track where an active track is a track currently being written to by one of the plurality of read/write heads. The active tracks are numbered 0 through 7 and a codeword quad is allocated to a particular active track identified by a track number using the following expression:

$$\text{Track_Number} = \text{Mod} \left[\frac{(\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T}))}{\text{N_T}}, \text{N_T} \right] \quad (2)$$

where CQ_Number is the number of the codeword quad to be allocated to an active track and can take the values 0 to 511. The Mod function returns the integer remainder of a modulo division. For example $\text{Mod}[N, 8]$ returns the integer values 0 to 7 for all integer values N. The above expression shall be referred to in the remainder of this description as expression (2).

[0040] The above expressions (1) and (2) are used in the default case, where no CQ sets are rewritten due to corrupted or poorly written CQ sets on the tape, and results in a write pattern as illustrated by example in Fig. 5 herein.

[0041] Referring to Fig. 6 herein which relates to an example where 8 tracks are written together, it is illustrated how codeword quads are distributed among active tracks in the case where no write errors occur. Tracks are represented as rows in Fig. 6, on a vertical axis, whilst successively written CQs are represented on a horizontal axis by their CQ numbers. The use of the above expression (2) ensures that C2 symbols from the same C2 codewords are contained in the

codeword quads that are distributed across the available active tracks. In Fig. 6 C2 parity codeword quads are represented by the shaded blocks. Once the codeword quads have been allocated to the active tracks, the 8 codeword quads which are written to tape simultaneously are known as a CQ set (also known as a Logical Track Block). The allocated codeword quads are then processed through a data randomizer which acts on each codeword pair within each codeword quad. The randomized byte stream is then encoded by a run length limited coding algorithm (RLL). The RLL encoded byte stream has synchronization information prior to writing to tape forming a synchronized codeword quads (SCQ). CQs which contain symbols for any specific C2 codeword are written physically in a diagonal line across the physical track on tape, as illustrated by shaded CQ boxes in Fig. 6 herein. The shaded boxes represent the CQs written to tape which contain the symbols from a single C2 codeword.

[0042] In order to maintain the integrity of the data written to tape, each of the plurality of read/write heads are configured such that data can be read back off an active track immediately after it has been written to that track. Write and Read operations occur simultaneously as the tape passes the read/write heads.

[0043] According to one aspect of the present invention there is provided a method of rewriting an CQ set which has been incompletely or badly written to tape wherein the order of the codeword quads within that SCQ set are rotated such that no rewritten codeword quad occupies the same active track as the previous, badly written, data.

[0044] Referring to Fig. 7 herein, there is illustrated schematically general process steps for rewriting corrupted codewords to tape, immediately after, or substantially simultaneously, with their initial writing to tape, during a same pass of the tape past the read/write heads. In step 700, user data is partitioned into the plurality of codewords as described hereinabove. In step 701, the codewords are distributed amongst the plurality of write heads as described hereinabove.

In step 702, the plurality of codewords are simultaneously written to a plurality of parallel physical tracks on the tape data storage medium, resulting in a sequence of codewords written on tape, an example of which is given in Fig. 6 herein. As the tape passes the read/write heads, codewords are continuously written to tape. Simultaneously with the writing of codewords to tape, as the tape passes the read head during the same pass of the tape past the read/write heads, the recently recorded codewords are read from the tape in parallel from the plurality of parallel physical tracks onto which they have been recorded, illustrated in step 703. In step 704, the read codewords are verified as being accurately recorded onto the tape. If, during the verification process, it is determined that the codewords as read from tape do not correspond with the codewords which were sent to the write head (ie the data has been incompletely written, or for some reason has been corrupted on the tape), then in step 705, the codewords affected by the corruption/incomplete writing are rewritten onto the plurality of tracks. Since new codewords are arriving at the write head during the read operation and the tape movement is continuous, the codewords which are to be rewritten are interleaved with current codewords which are being written by the write heads. The signals sent to the write heads comprise current codewords, interleaved with the re-write codewords. Interleaving of current codewords and re-write codewords may be effected by buffering the current codewords and re-write codewords together prior to recording on tape. Interleaving of the re-write codewords and the current codewords occurs in a buffer of the data storage device, arranged according to a microprocessor operated algorithm, operating as described hereunder.

[0045] Referring to Fig. 8 herein there are illustrated steps for writing a CQ set to a plurality of tracks, verifying that the data has been correctly written and rewriting badly written CQ sets. In step 801, the codeword quads forming one CQ set are allocated to particular active tracks using equation (2) of this description. In step 802, the codeword quads comprising the logical track block are written to tape. In step 803, the logical track block is read back off tape. In step 804, the data read off tape is checked for completeness. If no error has occurred on writing the data to tape, then the next codeword quads are allocated to the active tracks and steps 802, 804 are repeated. However, if a write error has occurred, then step 805 character W is incremented by 1. In step 806, the original codeword quads written to tape in step 802 are allocated to new active tracks using equation (3) with the incremented value of the counter represented by W. The reordered data is rewritten to tape in step 802 and steps 803 and 804 are repeated.

[0046] Each CQ set can be rewritten multiple times. In the example herein, the maximum number of CQ sets that may be rewritten within a single data set is 128. When an CQ set is rewritten, any CQ sets that have been written between the original and the rewritten version, do not need to be rewritten themselves unless one of the following conditions apply:

- An error is detected when they themselves are recorded.
- They have a data set number that is higher than that of the CQ set that is being rewritten.

[0047] If an error is detected by read while write verification when recording an CQ set, then that CQ set is rewritten further down the tape. The original, badly written, CQ set is left on the tape as written, (ie the tape is not re-wound to re-record over the incomplete or badly written data, but rather the tape passage continues uninterrupted and the corrupted data CQs are re-written). In the specific example described herein, no more than 6 other CQ sets may be written between the point at which the error was detected and when the CQ set in error is rewritten. The number of other CQ

sets written between the badly written CQ set and its rewritten version is fixed by the precise physical configuration of the read/write heads. The number of intermediate CQ sets also depends on the latency inherent to the read/write hardware of the device.

[0048] When a CQ set is repeated due to a detected write error, read whilst recording, the CQ within the affected CQ set in which the error occurs may be rotated around the tracks so that they do not appear on the same track as the previous time that they were written.

[0049] To effect such a rotation, the track number for each codeword quad in an SCQ set is given by the following equation:

$$\text{Track_Number} = \text{Mod} \left[\frac{(\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T}) - W, \text{N_T})}{\text{N_T}} \right] \quad (3)$$

where W is an arbitrary, but different, number between successive writings of the same SCQ set, W represents the state of a character which cycles through a sequence of integers 0 to M-1, where M represents the number of active tracks which can be written to simultaneously.

[0050] Referring to Fig. 9 herein there is shown an example of such a rotation in which a number of CQ sets are rewritten because an error was detected while they were being written. The notation K^X indicates that an error was detected while writing the CQ set K. The notation K' indicates that the CQ set K was rewritten once. The notation K'' indicates that the CQ set K was rewritten twice, etc. N is the said set number within the data set. Physical tracks 0 - 7 are represented as rows in Fig. 9, whilst written CQ sets are represented by W numbers extending horizontally.

[0051] Referring again to Fig. 2 herein, a data storage medium recorded with a set of Codeword Quads which have been erroneously written, and then re-written according to the above described method contains a set of Codeword Quads comprising a first logical track block written at a first position along a length of said tape, and said plurality of codewords comprising said first logical track block also re-written at a second position, further along said tape, at said second position, said Codeword Quads being reordered amongst said set of physical tracks 210-217 according to the expression (3) hereinabove. Reading of data recorded onto a magnetic tape in accordance with the above described method comprises passing the elongate past a plurality of read heads, such that all Codeword Quads of a logical track block are read simultaneously. If Codeword Quads are detected which have been erroneously written, the data is recovered from the same logical track block re-recorded further along the tape, in a second order as determined by the expression (3) above.

Claims

1. A method of writing data to a data storage medium the method characterized by comprising the steps of:
 - partitioning said data into a plurality of codewords (405, 407);
 - distributing said codewords amongst a plurality of write heads;
 - performing a write operation to write said codewords to a plurality of tracks of said data storage medium (702);
 - performing a read operation to read said codewords from said plurality of tracks (703);
 - if said codewords read from said plurality of tracks contain errors, then re-distributing said codewords originally written to said data storage medium in a different order amongst said plurality of write heads (804, 805); and
 - performing a re-write operation to re-write said re-distributed codewords to a plurality of tracks of said data storage medium (705).
2. The method as claimed in claim 1, wherein said data storage medium comprises an elongate tape, and said write operation comprises a write pass along a length of said tape.
3. The method as claimed in claim 1 or 2, wherein said step of distributing codewords amongst a plurality of write heads comprises distributing a plurality of Codeword Quads amongst said plurality of write heads.
4. The method as claimed in claim 3, wherein said step of distributing said Codeword Quads amongst said plurality

of write heads comprises:

allocating each of a plurality of Codeword Quads to a corresponding said

5 write head.

5. The method as claimed in claim 1, wherein said plurality of codewords are arranged into a plurality of Codeword Quads and said step of performing a write operation comprises simultaneously writing a plurality of Codeword Quads onto said data storage medium through said write heads.

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6. The method as claimed in claim 4 or 5, wherein said plurality of Codeword Quads are arranged into a logical track block for writing to said data storage medium simultaneously, and a position of an individual said Codeword Quad within said logical track block is indicated by an integer number.

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7. The method as claimed in claim 1, wherein:

said codewords are arranged into a plurality of Codeword Quads;

a plurality of said Codeword Quads to be written simultaneously are arranged into a logical track block;

20

said Codeword Quads of each said logical track block are allocated to corresponding ones of said plurality of write heads in a first order; and

25

if an error is detected in said Codeword Quads once written to said data storage medium, said Codeword Quads of said logical track block are re-allocated to said write heads in said different order.

8. The method as claimed in claim 7, wherein a position of said Codeword Quads within said logical track block is denoted by an integer number.

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9. The method as claimed in claim 7, wherein each of said Codeword Quads of a said logical track block corresponds with a respective one of said plurality of write heads.

10. The method as claimed in claim 7, wherein said first order is determined by the expression:

35

$$\text{Track_Number} = \text{Mod} \left[\frac{(\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T}))}{\text{N_T}}, \text{N_T} \right]$$

40

where the Track_Number represents a number of an element of a logical track block, CQ_Number represents a number of a set of four codewords, Mod represents the integer remainder of a modulo division; and N-T represents a number of tracks simultaneously written.

11. The method as claimed in any one of the preceding claims, wherein said different order is determined by an expression:

45

$$\text{Track_Number} = \text{Mod} \left[\frac{(\text{CQ_Number} - \text{Mod}(\text{CQ_Number}, \text{N_T}))}{\text{N_T}} - \text{W}, \text{N_T} \right]$$

50

where the Track_Number represents a number of an element of a logical track block, CQ_Number represents a number of a set of four codewords, Mod represents the integer remainder of a modulo division; W represents the state of a character which cycles through a sequence of integers 0 to M-1, where M represents the number of active tracks which can be written to simultaneously; and N-T represents a number of tracks simultaneously written.

55

12. The method as claimed in any one of the preceding claims, wherein said data storage medium comprises a magnetic data storage medium.

13. A data storage device comprising at least one read element and at least one write element, said device characterized by comprising means (201, 202) capable of writing data to a data storage medium and means (203, 204) capable of reading said written data from said data storage medium, wherein:

5 said write means is operable to partition said data into a plurality of codewords;

 said write means is operable to distribute said codewords amongst a plurality of write heads (220-227);

10 said write means is operable to perform a write operation to write said codewords to a plurality of tracks (210-217) of said data storage medium;

 said read means is operable to perform a read operation to read the codewords from said plurality of tracks;

15 if said codewords read from said plurality of tracks are incomplete, then said device is operable to re-distribute said codewords originally written to said data storage medium in a different order amongst said plurality of write heads; and

 said device is operable to perform a re-write operation to re-write said re-distributed codewords to a plurality of tracks of said data storage medium.

- 20 14. A device capable of reading data recorded on a data storage medium, said data comprising a plurality of codewords, said codewords having been written to said data storage medium in a plurality of track blocks, wherein each said track block comprises a plurality of codewords written to said data storage medium substantially simultaneously, wherein:

25 a plurality of codewords belonging to a first logical track block are written to a set of tracks in a first order, and

30 if said plurality of codewords have been erroneously written at said first position occupied by said logical track block, said plurality of codewords have been written to said plurality of tracks in a second order, at a second position on said plurality of tracks.

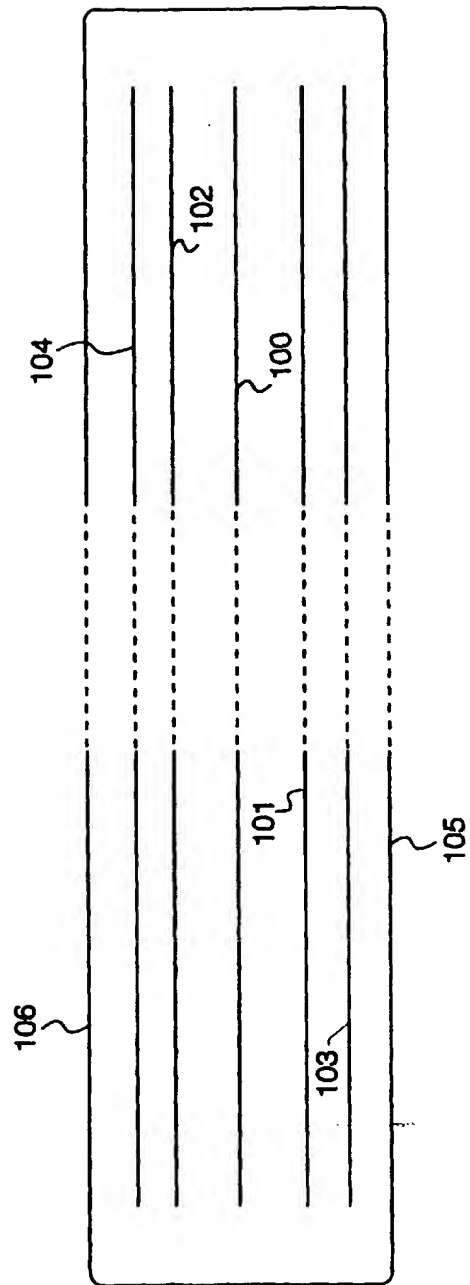


Fig. 1

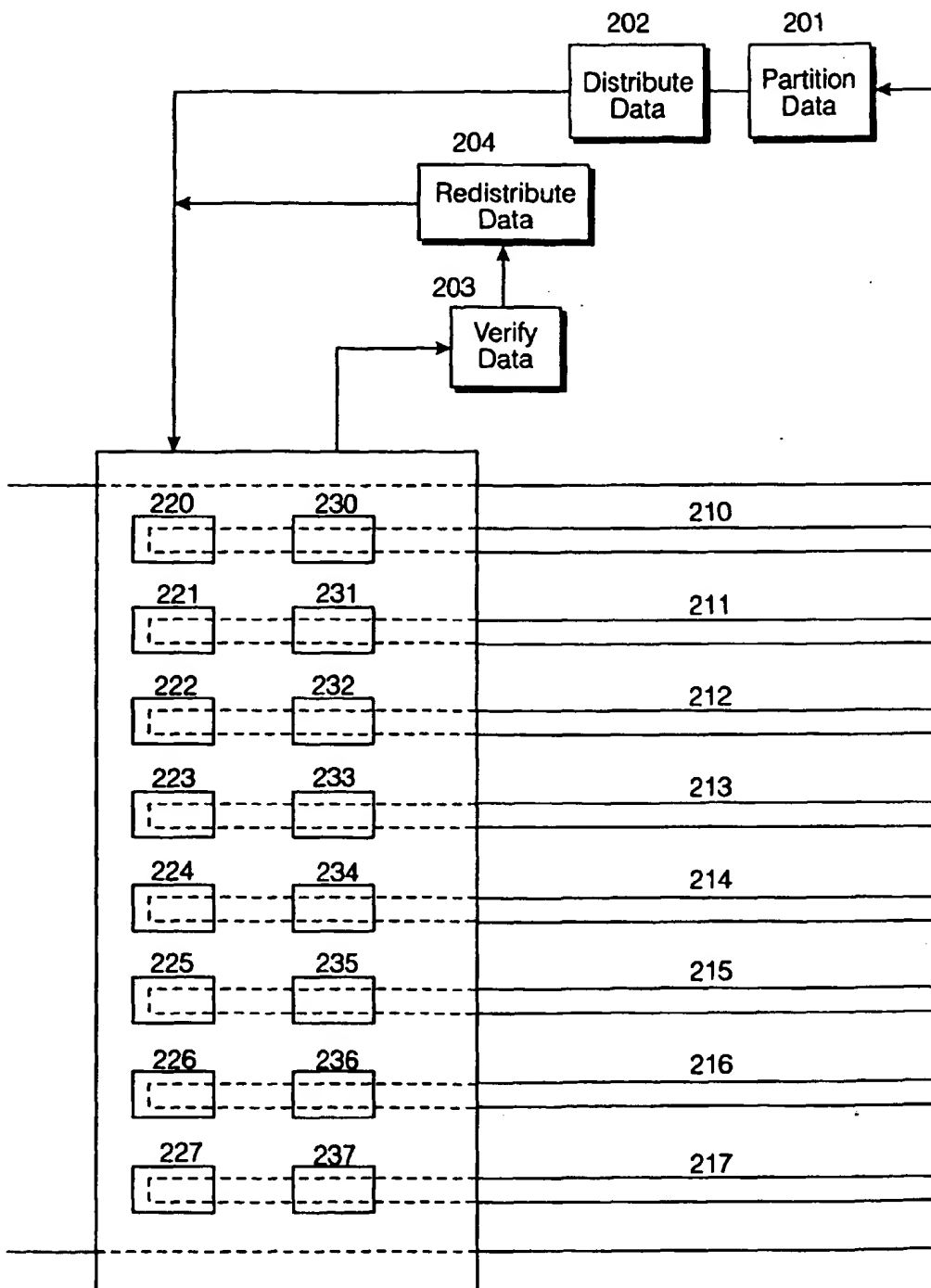


Fig. 2

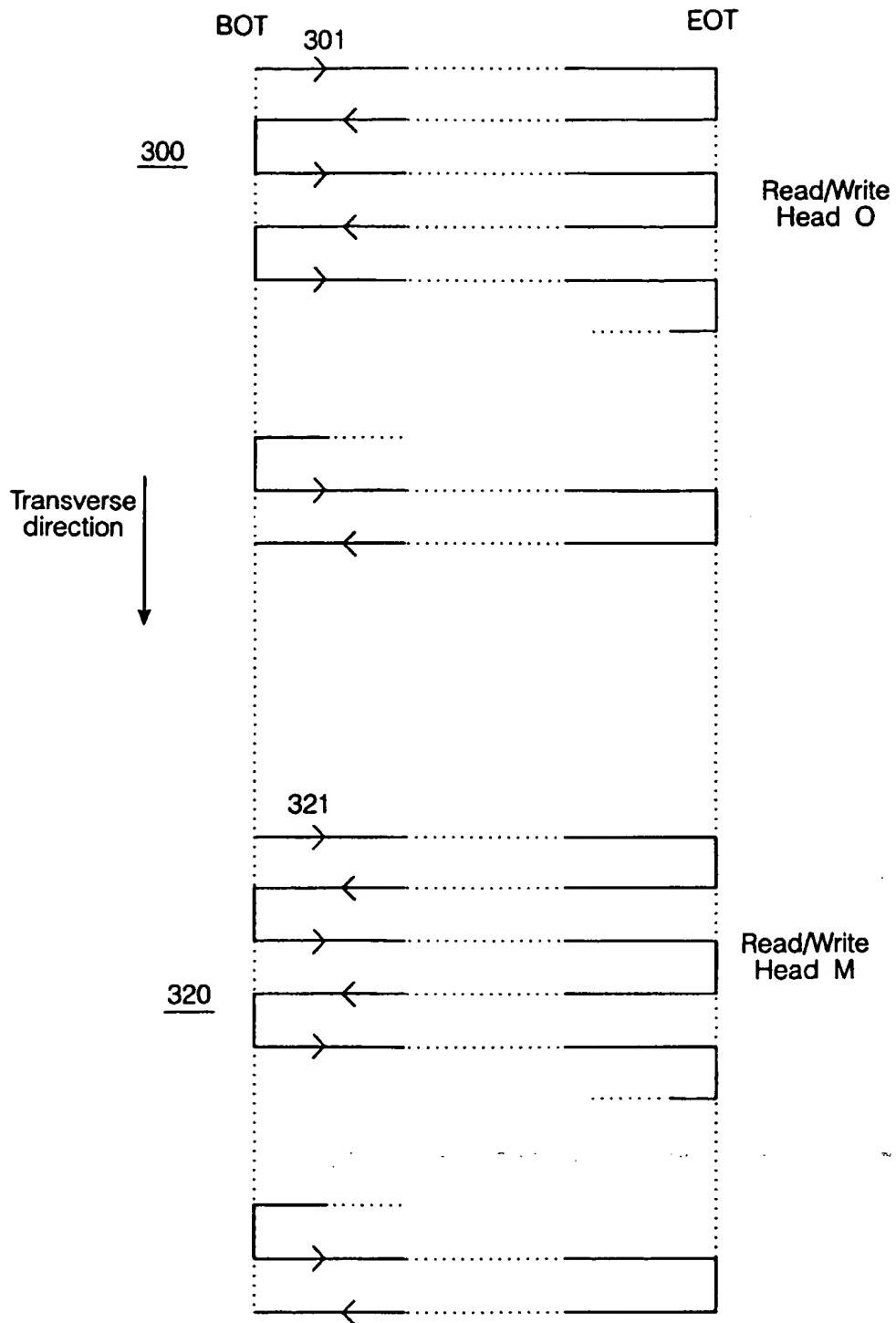


Fig. 3

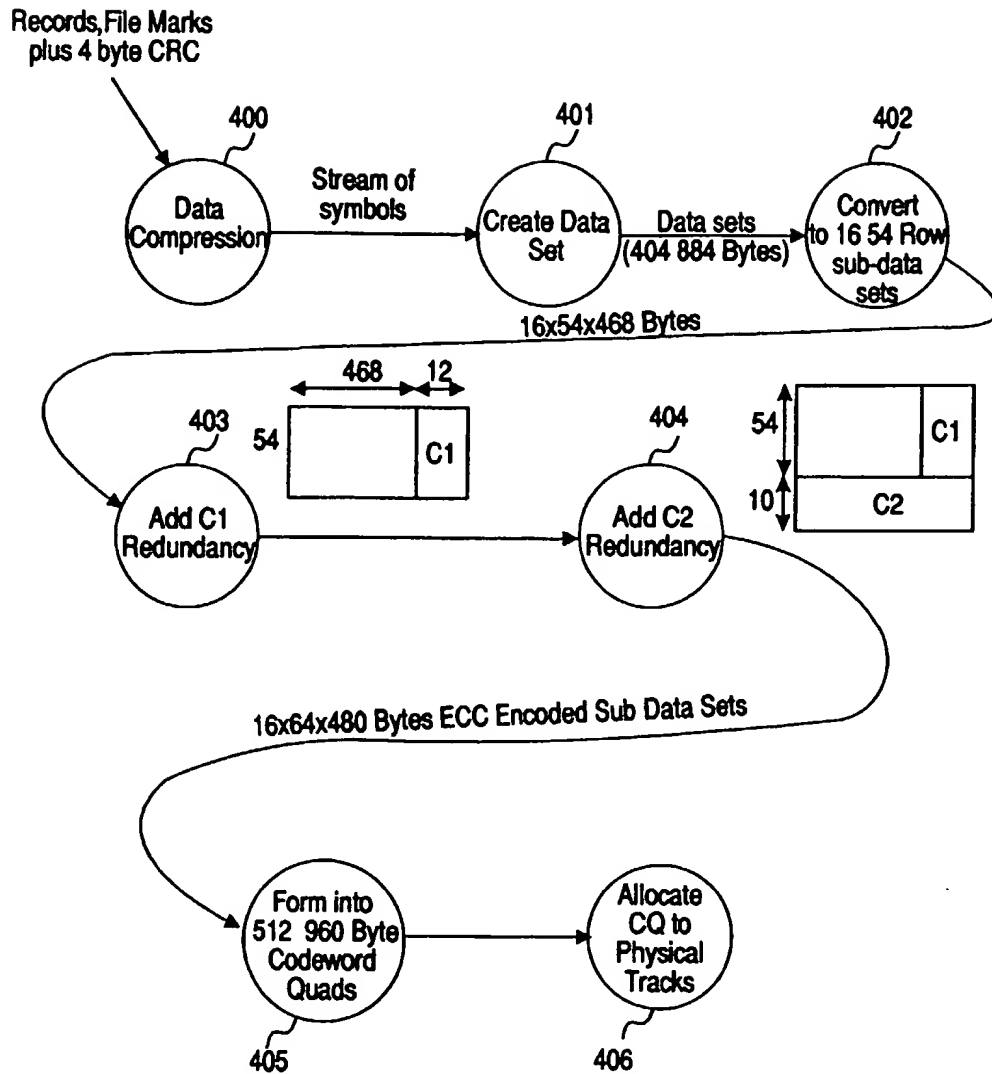


Fig. 4

500	501	510	511
Codeword Pair Header	First Codeword Pair	Codeword Pair Header	Second Codeword Pair

Fig. 5

0	9	18	27	36	45	54	63	64	82	..	438	447	448	457	466	475	484	493	502	511
1	10	19	28	37	46	55	56	65	83	..	439	440	449	458	467	476	485	494	503	504
2	11	20	29	38	47	48	57	66	84	..	432	441	450	459	468	477	486	495	496	505
3	12	21	30	39	40	49	58	67	85	..	433	442	451	460	469	478	487	488	497	506
4	13	22	31	32	41	50	59	68	86	..	434	443	452	461	470	479	480	489	498	507
5	14	23	24	33	42	51	60	69	87	..	435	444	453	462	471	472	481	490	499	508
6	15	16	25	34	43	52	61	70	80	..	436	445	454	463	464	473	482	491	500	509
7	8	17	26	35	44	53	62	71	81	..	437	446	455	456	465	474	483	492	501	510

Fig. 6

	W	0	0	0	1	1	1	2	2	2	2	3	3	3	3
Trk	N	0 ^x	1	2	0 ^x	3 ^x	4	0 ⁿ	3 ⁿ	5	6	3 ⁿ	7	8	9
0		0	9	18	1'	27	36	2 ⁿ	29'	45	54	30 ⁿ	63	64	27
1		1	10	19	2'	28	37	3 ⁿ	30'	46	55	31 ⁿ	56	65	74
2		2	11	20	3'	29	38	4 ⁿ	31'	47	48	24 ⁿ	57	66	75
3		3	12	21	4'	30	39	5 ⁿ	24'	40	49	25 ⁿ	58	67	76
4		4	13	22	5'	31	32	6 ⁿ	25'	41	50	26 ⁿ	59	68	77
5		5	14	23	6'	24	33	7 ⁿ	26'	42	51	27 ⁿ	60	69	78
6		6	15	16	7'	25	34	0 ⁿ	27'	43	52	28 ⁿ	61	70	79
7		7	8	17	0'	26	35	1 ⁿ	28'	44	53	29 ⁿ	62	71	72

Fig. 7

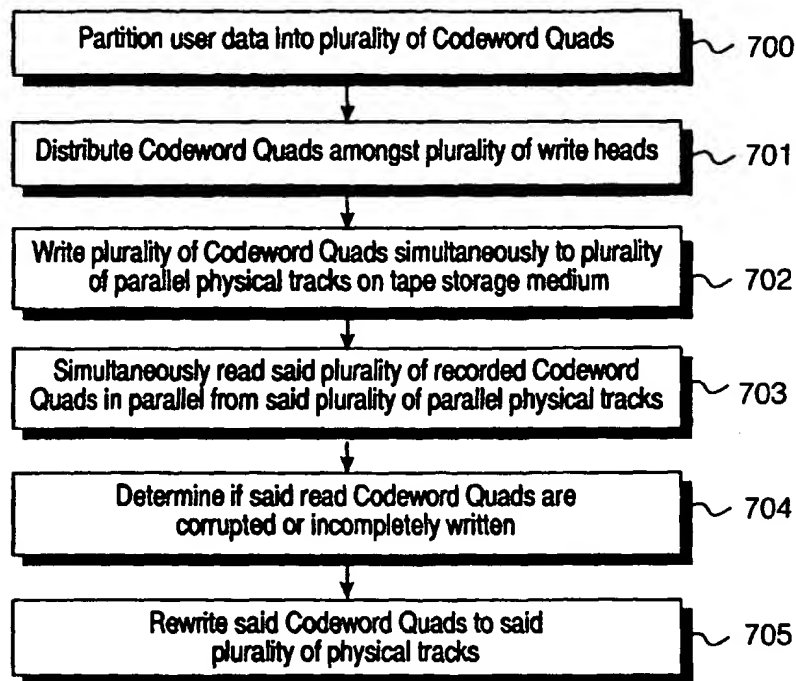


Fig. 7

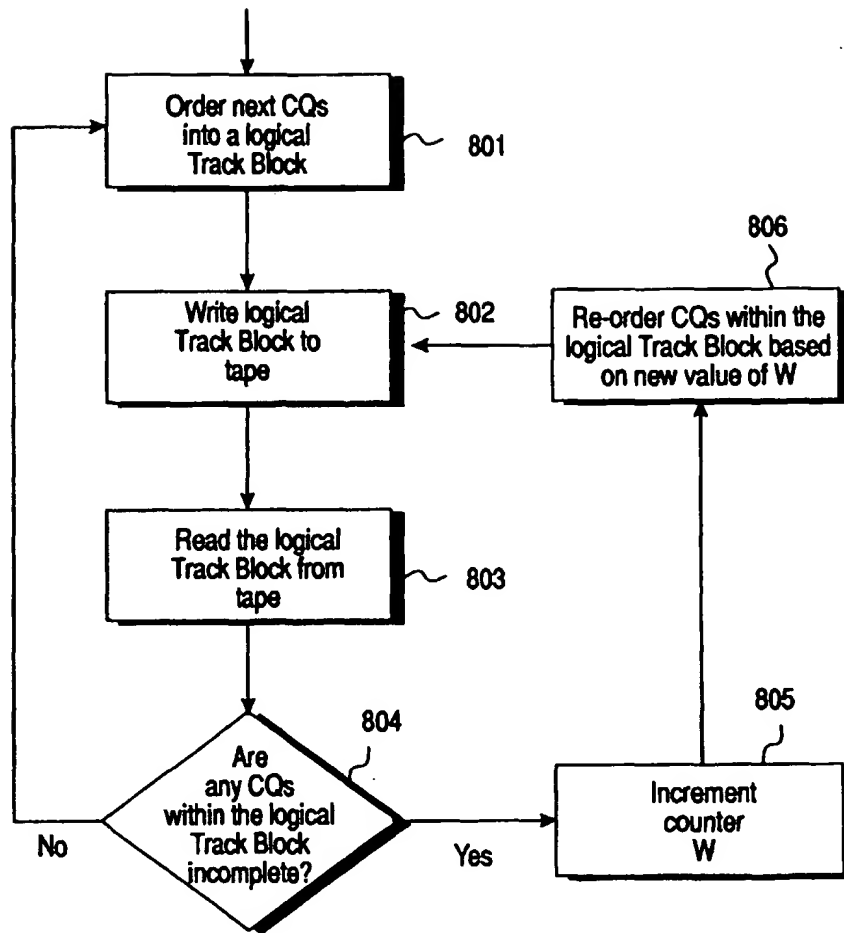


Fig. 8



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 3691

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GAST J: "NEW 8 MM IS IDEAL FOR AUTOMATED STORAGE EVERYTHING YOU WANTED TO KNOW ABOUT 8MM - AND MORE" COMPUTER TECHNOLOGY REVIEW, vol. 11, no. 3, 1 March 1991, pages 26, 28-29, XP000224983 * page 26, column 1, line 50 - column 2, line 49 *	1,2,13, 14	G11B20/18 G11B5/02 G11B5/008
A	EP 0 793 228 A (QUANTUM CORP) 3 September 1997 * column 1, line 23 - line 57 * * column 6, line 16 - column 7, line 43 * * claims 1-7; figures 2-4 *	1-7,9, 12-14	
A	US 4 637 023 A (LOUNSBURY DAVID M ET AL) 13 January 1987 * abstract; figures 1-4 * * column 2, line 47 - column 3, line 25 * * column 4, line 39 - column 6, line 13 * * column 9, line 59 - column 13, line 41 *	1-3,13, 14	
A	WO 89 00312 A (EXABYTE CORP) 12 January 1989 * page 1, line 22 - page 2, line 32 * * page 6, line 15 - page 7, line 19 * * page 22, line 20 - page 23, line 17 * * page 30, line 3 - page 31, line 13 * * claims 1,2; figure 11 *	1-9, 12-14	
A	US 5 499 147 A (TSAI JANG-ZERN ET AL) 12 March 1996 -----		
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 22 October 1998	Examiner Schiwy-Rausch, G
CATEGORY OF CITED DOCUMENTS X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document		T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons &: member of the same patent family, corresponding document	

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